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STREAM FLOW CHARACTERISTICS OF MOUNTAIN STREAMS IN THE UPPER YELLOWSTONE RIVER BASIN IN MONTANA

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15	Eightmile Creek	22
16	Mill Creek	22
17	Deep Creek	22
18	Trail Creek	23
19	Suce Creek	23

CONVERSION FACTORS

The following factors can be used to convert inch-pound units in this report to the International System of units (SI).

Multiply inch-pound unit	By	To obtain SI unit
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

STREAMFLOW CHARACTERISTICS OF MOUNTAIN STREAMS IN THE UPPER YELLOWSTONE RIVER BASIN IN MONTANA

By

Charles Parrett

ABSTRACT

Once-monthly streamflow measurements were used to estimate long-term mean annual discharge, mean monthly discharge, and various points on the flow-duration curve for 17 sites in the upper Yellowstone River basin in Montana. The estimated average error when estimating long-term mean annual discharge and various discharges on the flow-duration curve was ±20 percent at the measurement sites. The estimated average error when estimating long-term mean monthly discharge at the measurement sites was ±100 percent. The estimated flow characteristics at the measurement sites, together with data from one gaging station, were used to develop a map showing the variability of mean annual runoff in the study area.

Data from the measurement sites plus data from one gaging station were used to develop regression equations relating mean annual discharge to drainage area and precipitation and equations relating flows of 10-, 20-, 30-, 40-, 50-, 60-, 70-, 80-, 90-, and 95-percent exceedance probability to mean annual discharge. The coefficient of determination for the best equation for predicting mean annual discharge was 0.896. The coefficients of determination for the equations for flows of various exceedance percentages ranged from 0.616 to 0.948.

INTRODUCTION

Increased interest in the development of small hydropower-generation facilities on small mountain streams has spurred efforts to improve techniques for estimating streamflow characteristics at potential hydropower facility sites. Thus, a recent study by the U.S. Geological Survey (1985) used once-monthly streamflow measurements on mountain streams in western Montana (Columbia River basin) to estimate long-term mean annual discharge, mean monthly discharge, and flow-duration curves at the measurement sites. The streamflow characteristics thus determined were used with streamflow-gaging station data to develop regression equations for estimating streamflow at any potential hydropower site in western Montana.

In addition to that study, a program of once-monthly streamflow measurements was recently completed in the upstream part of the Yellowstone River basin. This program, conducted by the U.S. Geological Survey in cooperation with the Montana Department of Fish, Wildlife and Parks, had the objective of providing estimates of certain monthly streamflow characteristics for selected streams under provisions of the Yellowstone River flow reservation (Montana Department of Fish, Wildlife and Parks 1983). Because most of these streams are mountain streams that also may have potential for small hydropower development, the flow-measurement data collected for the Department of Fish, Wildlife and Parks were used to make the same

kind of analysis for the upstream part of the Yellowstone River basin as was done for the western Montana hydropower study.

This report presents the streamflow data collected and streamflow characteristics determined from the analysis of the data. Estimates of long-term mean annual discharge, mean monthly discharge, and various points on the flow-duration curve were developed for each measurement site in the upper Yellowstone River basin. The estimated streamflow characteristics then were used to develop regression equations for estimating streamflow characteristics at any potential hydropower site in the upstream part of the Yellowstone River basin. This report and the analysis were done in cooperation with the Energy Division of the Montana Department of Natural Resources and Conservation.

DESCRIPTION OF STUDY AREA

The study area (figure 1) is described throughout this report as the upstream part of the Yellowstone River drainage. It includes only that part of the Yellowstone River drainage in Montana between Yellowstone National Park and Livingston.

The Yellowstone River flows generally north through the study area and is bordered on the west by mountains of the Gallatin Range and on the east by mountains of the Absaroka Range. The mountains on both sides are rugged and mostly forested. Several peaks on each side exceed 10,000 feet in elevation, and much of the area higher than 8,000 feet is above the timberline.

Mean annual precipitation varies greatly in the study area, ranging from about 14 inches on the valley floor to more than 40 inches in the higher mountains. Although most of this precipitation falls as winter snow, significant rain commonly falls in May and June.

Annual runoff generally follows the precipitation pattern, with greater quantities in higher areas. Streamflow varies greatly on a seasonal basis with snowmelt providing most of the annual runoff in May, June, and July. The smallest streamflow generally occurs during the winter when base flow is entirely the result of ground-water inflow.

MEASUREMENT SITES, GAGING STATIONS, AND AVAILABLE STREAMFLOW DATA

Seventeen streamflow-measurement sites were established and used for determining streamflow characteristics at potential hydropower sites in the upper Yellowstone drainage. In addition, two streamflow-gaging stations (station 4, Yellowstone River at Corwin Springs, and station 12, Big Creek near Emigrant) were used as comparison stations for estimating mean discharge at the measurement sites. Locations of the measurement sites and gaging stations are shown in figure 1. Descriptions of the measurement sites and gaging stations, and the monthly streamflow measurements, are given at the end of the report.

Streamflow measurements were begun in November 1982 and continued through October 1983. The streamflow record for the Yellowstone River at Corwin Springs (station 4) is available for wateryears 1889 to 1893 and 1910 to the present (1984). For Big Creek near Emigrant (station 12), the available flow record is for wateryears 1974 to 1979 and 1983. Streamflow record for two wateryears also is availa-

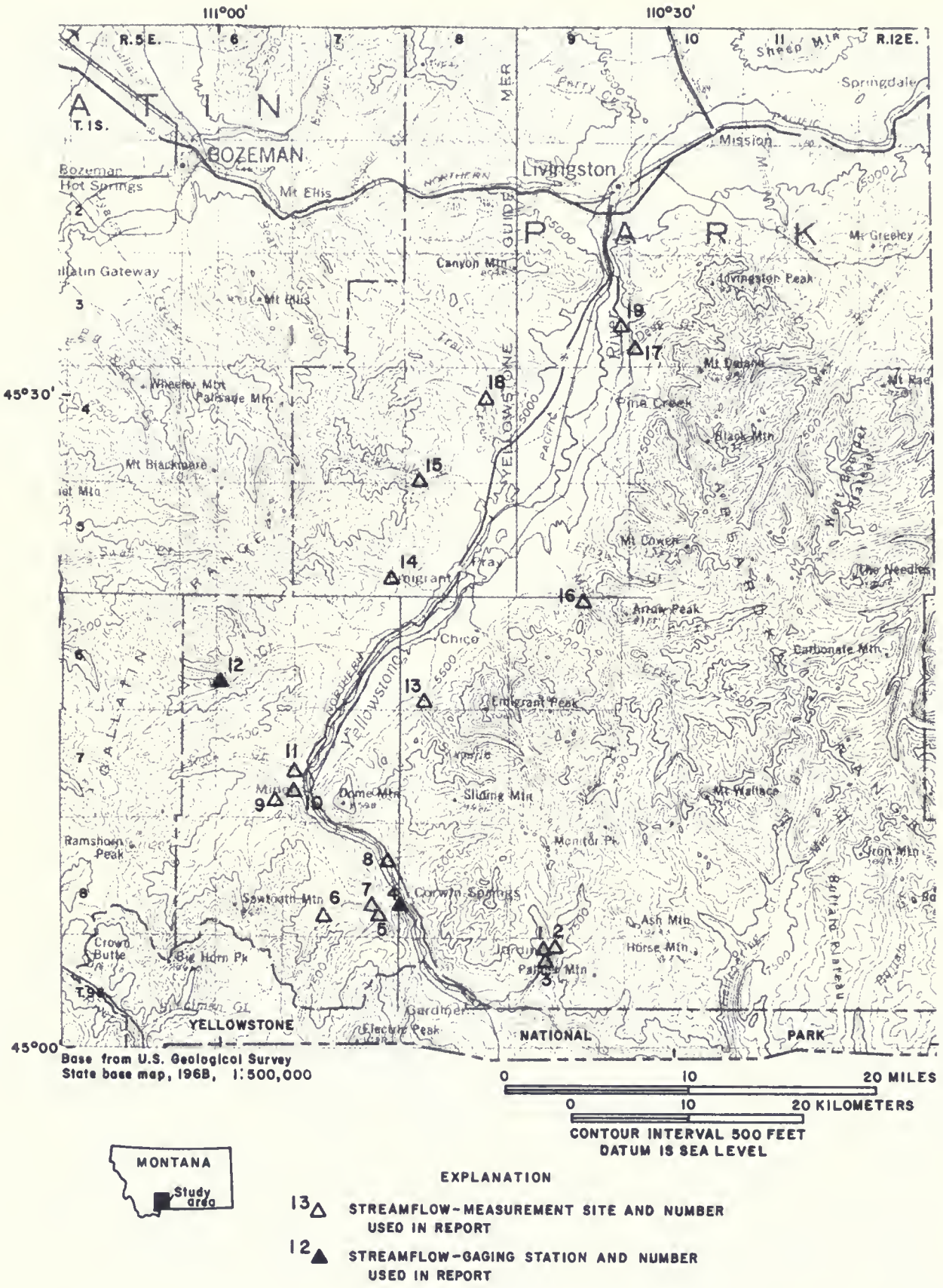

Figure 1.--Location of study area, streamflow-measurement sites, and streamflow-gaging stations.

ble at the Bear Creek near Jardine measurement site (site 3), but these data were used only for checking the accuracy of the flows estimated for Bear Creek. The streamflow record for 1951 to 1956 is available for Mill Creek about a mile downstream from site 16 and downstream from several large irrigation diversions. Therefore, this record was used only to check the accuracy of the monthly mean discharge estimates for the months when irrigation did not occur.

ESTIMATING STREAMFLOW CHARACTERISTICS

Methods of analysis

To assure that all streamflow estimates were based on a common period of record, a streamflow correlation program (HEC-4) developed by the U.S. Army Corps of Engineers (1971) was used to extend the record of Big Creek to wateryears 1934-83. Likewise, only the record for wateryears 1934-83 on the Yellowstone River at Corwin Springs was used to determine streamflow characteristics at that gaging station. The adjusted streamflow characteristics at the two gaging stations are presented in table 1.

Table 1.--Adjusted streamflow characteristics at gaging stations

[ft^3/s, cubic feet per second]

Gaging station No. (fig. 1)	Stream	Mean annual discharge, period of record (ft^3/s)	Mean annual discharge, water years 1934-83 (ft^3/s)	Discharge, in cubic feet per second, for indicated exceedance percentage (water years 1934-83)									
				10	20	30	40	50	60	70	80	90	95
4	Yellowstone River	3,120	3,095	8,480	4,640	2,690	1,840	1,410	1,170	1,020	891	756	660
12	Big Creek	64.5	62.0	170	76.4	43.4	35.0	31.0	27.8	25.1	23.2	21.7	20.0

The method proposed by Riggs (International Association of Scientific Hydrology 1969) was used to estimate the annual (November 1982-October 1983) mean discharge at each measurement site. A similar procedure described by Parrett and Hull (U.S. Geological Survey 1985) was used to estimate discharges for various exceedance percentages. An example of the computation of an annual mean discharge is provided in table 2, and concurrent discharges at two sites are illustrated in figure 2. Likewise, an example of the computation of a flow-duration curve is given in table 3 and illustrated in figure 3. At one site (Eightmile Creek, site 15) computation of a flow-duration curve was not possible because of excessive scatter of the plotted points; hence table 3 shows no computed discharges for that site. It should be noted that the computation procedure (table 3 and figure 3) provides a flow-duration curve for the adjusted period, wateryears 1934-83, and not the original period of record at the comparison gage. In this respect, this report differs from the report for western Montana (U.S. Geological Survey 1985).

Table 2.--Computation of annual mean discharge for Tom Miner Creek above Canyon Creek (site 9)

[ft^3/s, cubic feet per second]

Date	Big Creek near Emigrant (gaged)			Tom Miner Creek (ungaged)	
	Recorded daily mean discharge[1] (ft^3/s)	Monthly mean discharge (ft^3/s)	Ratio of monthly mean to daily mean	Measured discharge[1] (ft^3/s)	Estimated monthly mean discharge (ft^3/s)
11-16-82	30	29.0	0.97	53.0	51.4
12-14-82	27	25.1	.93	28.9	26.9
01-19-83	23	23.4	1.02	23.5	24.0
02-15-83	22	22.1	1.00	21.2	21.2
03-15-83	24	23.0	.96	29.1	27.9
04-13-83	22	30.5	1.39	27.1	37.7
05-17-83	33	82.9	2.51	49.1	123
06-01-83	202	228	1.13 } [2]1.12	168 } [2]166	
06-15-83	206	228	1.11 }	164 }	186
07-13-83	119	109	.92	97.2	89.4
08-15-83	40	40.7	1.02	52.6	53.7
09-15-83	28	30.7	1.10	30.7	33.8
10-13-83	32	33.8	1.06	35.0	37.1
			Estimated annual mean discharge		59.4

[1] Data used to prepare figure 2.
[2] Mean value based on two June discharges.

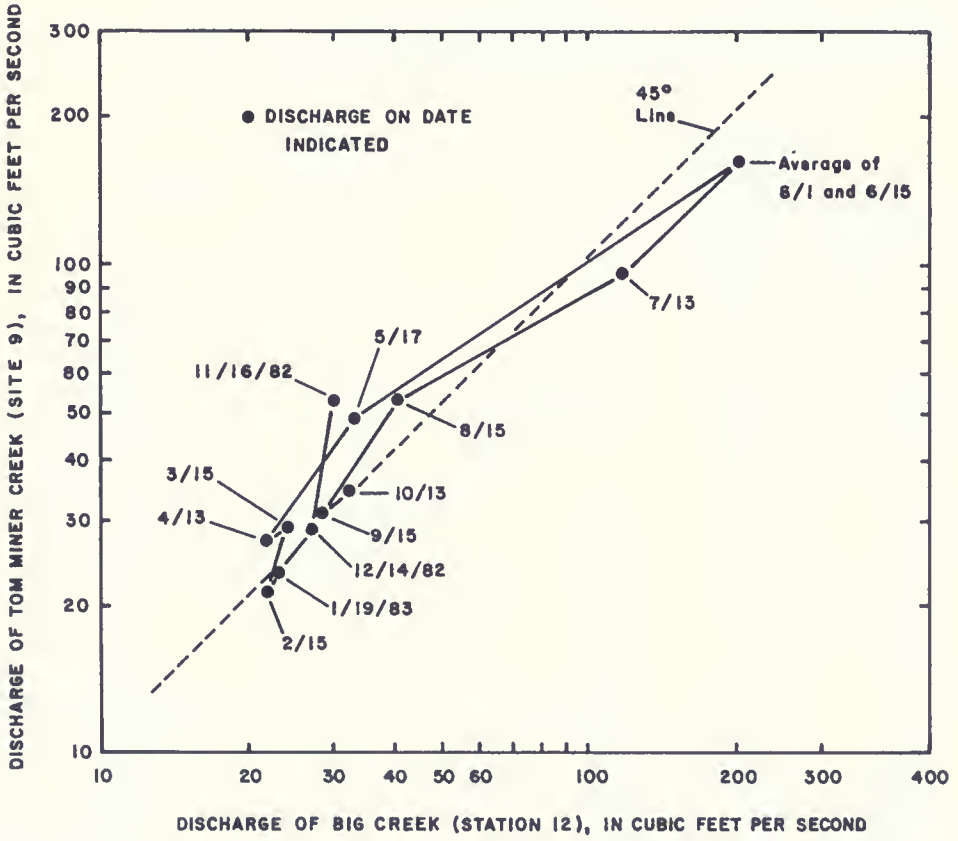

Figure 2.--Concurrent discharges of Tom Miner Creek above Canyon Creek (site 9) and Big Creek near Emigrant (station 12).

Table 3.--Computation of flow-duration curve for Tom Miner Creek above Canyon Creek (site 9)

[ft^3/s, cubic feet per second]

Date	Big Creek near Emigrant (gaged)		Tom Miner Creek (ungaged)
	Recorded daily mean discharge (ft^3/s)	Exceedance percentage[1,2]	Measured discharge[1] (ft^3/s)
11-16-82	30	52	53.0
12-14-82	27	64	28.9
01-19-83	23	82	23.5
02-15-83	22	87	21.2
03-15-83	24	76	29.1
04-13-83	22	87	27.1
05-17-83	33	48	49.1
06-01-83	202	8.5	168
06-15-83	206	7.5	164
07-13-83	119	15	97.2
08-15-83	40	32	52.6
09-15-83	28	60	30.7
10-13-83	32	47	35.0

[1] Data used to prepare figure 3.
[2] From Big Creek flow-duration curve.

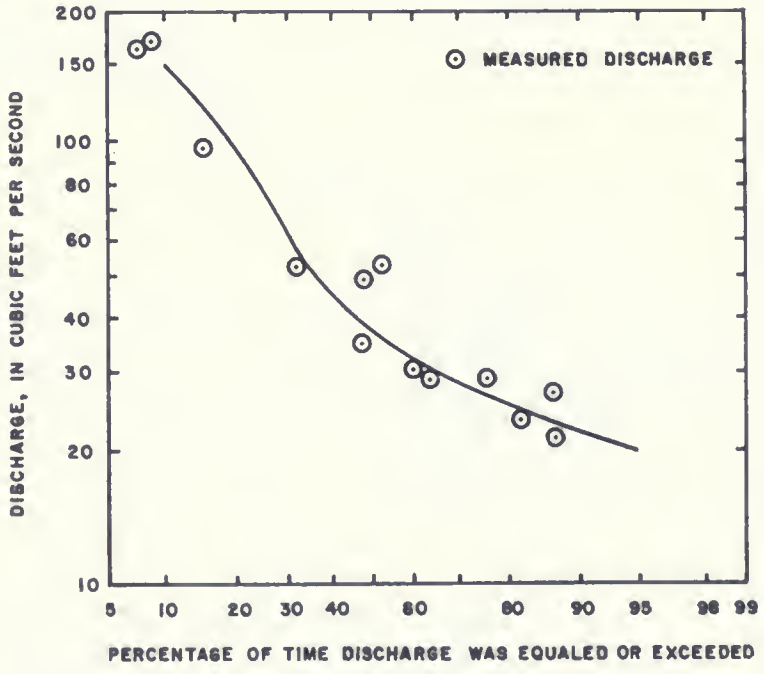

Figure 3.--Estimated flow-duration curve for Tom Miner Creek above Canyon Creek (site 9).

To convert the annual mean discharge for November 1982-October 1983 to a long-term mean annual discharge, the ratio of the long-term mean annual discharge to the November 1982-October 1983 annual mean discharge was computed for the two comparison gaging stations. The two ratios (1.02 for the Yellowstone River at Corwin Springs and 1.10 for Big Creek near Emigrant) were then averaged to obtain a simple ratio for the entire study area. This ratio was then multiplied by each calculated annual mean discharge at the measurement sites to yield an estimate for long-term mean annual discharge.

Estimates of mean monthly discharge were made by assuming that the monthly distribution of long-term mean annual discharge was the same at each measurement site as at Big Creek near Emigrant. Thus, for example, the mean monthly discharge for Big Creek for July is 104 ft^3/s. This figure is 1.68 times the mean annual discharge of 62.0 ft^3/s. At each measurement site, the long-term July discharge thus is assumed to be 1.68 times the mean annual discharge previously computed. Adjustments were made to the computed mean monthly discharges when the computed values for the low-flow months differed substantially from the measured discharges for those months. For example, the computed monthly means for Deep Creek (site 17) were changed for the low-flow months because measured discharges for fall and winter months indicated that base flow was a smaller percentage of the mean annual discharge than at the Big Creek gage. The streamflow characteristics estimated for each measurement site and the streamflow characteristics at the two comparison gaging stations are presented in tables 4-6.

Table 4.--Basin characteristics and mean annual discharge for streamflow-measurement sites (1934-83 base period)

[mi^2, square miles; ft^3/s, cubic feet per second]

Site No.	Stream name and gaging-station number	Drainage area (mi^2)	Mean annual precip-itation (inches)	Mean annual discharge (ft^3/s)	Mean annual runoff (inches)
1	North Fork Bear Creek	13.4	[1]33	22.6	22.9
2	Bear Creek above North Fork	13.8	[1]33	37.3	36.7
3	Bear Creek	27.2	[1]33	60.0	29.9
4	Yellowstone River at Corwin Springs (06191500)	2,623	33	3,095	16.0
5	Mol Heron Creek	18.1	34	24.4	18.3
6	Cinnabar Creek above Cottonwood Cr.	14.5	38	10.7	10.0
7	Cinnabar Creek at mouth	23.9	34	12.7	7.2
8	Cedar Creek	21.3	27	9.16	5.8
9	Tom Miner Creek above Canyon Creek	55.9	37	63.0	15.3
10	Tom Miner Creek at mouth	65.8	35	57.2	11.8
11	Rock Creek	28.8	37	23.3	11.0
12	Big Creek near Emigrant (06191800)	60.9	36	62.0	13.8
13	Sixmile Creek	33.8	28	34.0	13.7
14	Fridley Creek	17.2	37	19.8	15.6
15	Eightmile Creek	27.1	37	24.9	12.4
16	Mill Creek	148	33	160	14.7
17	Deep Creek	18.8	30	12.7	9.2
18	Trail Creek	41.8	26	20.7	6.7
19	Suce Creek	9.77	23	6.36	8.8

[1]Values considered to be incorrect. See text for discussion.

Table 5.--Daily mean discharges for selected exceedance percentages at streamflow-measurement sites and streamflow-gaging stations

Site or station No. (fig. 1)	Stream name and gaging-station number	Mean daily discharge, in cubic feet per second, for indicated exceedance percentage									
		10	20	30	40	50	60	70	80	90	95
1	North Fork Bear Creek	79.0	44.5	27.3	17.8	12.2	8.5	6.0	4.2	2.8	2.2
2	Bear Creek above North Fork.	138.0	75.5	42.5	24.0	14.2	9.0	6.0	4.1	2.8	2.3
3	Bear Creek	155.0	120.0	67.0	36.5	20.8	13.6	9.5	7.0	5.4	4.7
4	Yellowstone River (06191500).	8,480.0	4,640.0	2,690.0	1,840.0	1,410.0	1,170.0	1,020.0	891.0	756.0	660.0
5	Mol Heron Creek	60.0	39.5	28.0	20.5	15.8	12.7	10.2	8.4	6.9	6.0
6	Cinnabar Creek above Cottonwood Creek.	26.0	18.8	13.8	10.2	8.2	6.7	5.6	4.7	4.0	3.7
7	Cinnabar Creek at mouth	26.0	19.0	14.3	11.2	9.4	8.2	7.3	6.5	5.7	5.2
8	Cedar Creek	23.3	17.1	12.8	9.6	7.2	5.1	3.6	2.4	1.5	1.1
9	Tom Miner Creek above Canyon Creek.	150.0	95.5	62.5	45.0	37.5	32.0	28.3	25.0	21.8	19.8
10	Tom Miner Creek at mouth	145.0	90.0	62.5	48.5	39.5	32.5	27.5	22.5	17.5	14.5
11	Rock Creek	101.0	48.5	25.0	14.8	9.9	7.3	5.6	4.6	4.0	3.7
12	Big Creek (06191800)	170.0	76.4	43.4	35.0	31.0	27.8	25.1	23.2	21.7	20.0
13	Sixmile Creek	110.0	53.0	30.0	21.0	15.0	11.8	9.6	7.9	6.7	6.0
14	Fridley Creek	51.0	32.5	23.0	17.0	13.0	10.3	8.3	6.7	5.5	4.9
15	Eightmile Creek	--	--	--	--	--	--	--	--	--	--
16	Mill Creek	510.0	255.0	148.0	95.0	65.0	46.5	34.5	26.0	20.0	17.5
17	Deep Creek	74.0	11.8	3.4	1.6	1.0	.7	.5	.5	.4	.3
18	Trail Creek	45.0	29.5	21.0	16.0	12.4	9.8	7.7	6.1	4.7	3.9
19	Suce Creek	23.5	8.1	3.9	2.4	1.6	1.2	.9	.7	.6	.6

Table 6.--Mean monthly discharges at streamflow-measurement sites and streamflow-gaging stations

Site or station No. (fig. 1)	Stream name and gaging-station number	Mean monthly discharge, in cubic feet per second, for indicated month											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	North Fork Bear Creek.	5.5	5.0	5.0	7.5	52.0	100.0	50.0	19.0	7.0	6.5	6.5	6.0
2	Bear Creek above North Fork.	7.5	7.5	8.0	10.5	73.0	170.0	80.0	31.0	28.0	18.5	9.5	7.0
3	Bear Creek	13.0	12.5	13.0	18.0	125.0	270.0	130.0	50.0	35.0	25.0	16.0	13.0
4	Yellowstone River (06191500).	783.0	780.0	854.0	1,450.0	5,960.0	11,600.0	7,010.0	3,210.0	1,960.0	1,470.0	1,140.0	916.0
5	Mol Heron Creek	9.1	8.7	9.5	16.2	48.4	93.3	43.3	16.1	13.0	12.6	11.0	9.8
6	Cinnabar Creek above Cottonwood Creek.	4.0	3.8	4.2	7.1	21.2	40.9	19.0	7.1	5.7	5.5	4.8	4.3
7	Cinnabar Creek at mouth.	4.7	4.5	4.9	8.4	25.2	48.6	22.5	8.4	6.8	6.6	5.7	5.1
8	Cedar Creek	3.4	3.3	3.6	6.1	18.2	35.0	16.2	6.1	4.9	4.7	4.1	3.7
9	Tom Miner Creek above Canyon Creek.	23.4	22.3	24.4	41.7	125.0	241.0	112.0	41.7	33.5	32.5	28.4	25.4
10	Tom Miner Creek at mouth.	21.2	20.3	22.2	37.9	113.0	219.0	101.0	37.8	30.4	29.5	25.8	23.0
11	Rock Creek	8.6	8.3	9.0	15.4	46.2	89.1	41.3	15.4	12.4	12.0	10.5	9.4
12	Big Creek (06191800)	23.1	21.7	24.2	41.8	123.0	240.0	106.0	41.0	32.2	32.2	29.0	25.5
13	Sixmile Creek	10.6	10.1	11.2	20.5	70.5	135.0	63.3	22.5	17.1	16.5	14.3	13.7
14	Fridley Creek	7.3	7.0	7.7	13.1	39.3	75.7	35.1	13.1	10.5	10.2	8.9	8.0
15	Eightmile Creek	15.0	14.0	14.0	17.0	45.0	76.8	40.0	16.0	16.0	15.0	15.0	15.0
16	Mill Creek	31.4	30.2	27.3	57.1	294.0	785.0	350.0	140.0	85.0	39.0	40.9	40.2
17	Deep Creek	.7	.7	1.0	2.0	32.0	80.0	26.5	3.0	2.0	1.5	1.5	1.0
18	Trail Creek	7.7	7.3	8.0	18.7	51.1	69.1	31.7	13.7	11.0	10.7	9.3	8.3
19	Suce Creek	2.4	2.3	2.5	4.2	12.6	24.3	11.3	4.2	3.4	3.3	2.9	2.6

[1] Monthly discharges based on flow record at discontinued gaging station (06192000) for January, February, March, April, May, October, November, and December.

Appraisal of accuracy

The accuracy of the streamflow estimates made at the ungaged measurement sites cannot be determined directly. An indication of accuracy can be made, however, by applying the estimation technique to one of the gaging stations in the study area. Accordingly, Big Creek near Emigrant (station 12) was selected as the station for which estimates were required, and the Yellowstone River at Corwin Springs (station 4) was used as the comparison station. The results of the estimating procedure using wateryear 1975 are given in tables 7-9. Based on the results in tables 7-9, it appears that long-term mean annual discharge and the flow-duration curve can be estimated with an expected average error of about 20 percent. Mean monthly discharge can be estimated with an expected error ranging from about -18 to about +117 percent.

Table 7.--Computation of long-term mean annual discharge at Big Creek near Emigrant (station 12)

[ft^3/s, cubic feet per second]

	Yellowstone River			Big Creek			
Date	Daily mean discharge (ft^3/s)	Exceedance percentage[1]	Monthly mean discharge (ft^3/s)	Daily mean discharge[2] (ft^3/s)	Estimated monthly mean discharge (ft^3/s)	Actual monthly mean discharge (ft^3/s)	Percent difference
10-15-74	1,490	48	1,521	33	33.7	33.8	0
11-15-74	1,140	61	1,160	35	35.6	36.9	-4
12-15-74	975	72	962	30	29.6	27.5	+8
01-15-75	750	91	765	23	23.5	24.3	-3
02-15-75	707	94	721	23	23.5	42.6	-45
03-15-75	953	74	948	23	22.9	23.1	-1
04-15-75	1,070	65	1,044	25	24.4	25.7	-5
05-15-75	2,590	31	2,575	154	153	91.2	+68
06-15-75	14,800	3	11,610	325	255	285	-10
07-15-75	12,600	4	12,470	286	283	292	-3
08-15-75	4,210	22	4,371	60	62.3	59.1	+5
09-15-75	2,280	34	2,327	31	31.6	34.2	-8
Annual mean discharge (wateryear 1975)			3,388		81.9	81.5	0
Long-term mean annual discharge (wateryears 1934-83)			3,095		74.8	62.0	+21

[1] From Yellowstone River flow-duration curve.

[2] Determined from ratio of annual mean discharge for wateryear 1975 to long-term mean annual discharge of Yellowstone River.

Table 8.--Estimated error in flow duration at Big Creek near Emigrant (station 12)

Exceedance percentage[1]	Daily mean discharge of Big Creek, in cubic feet per second: Estimated	Actual	Percent difference
95	16	20	-20
90	18	21	-14
80	21	23	-9
70	25	25	0
60	31	28	+11
50	39	31	+26
40	51	35	+46
30	70	47	+49
20	108	77	+40
10	187	170	+10
		Average error =	+14

[1] From data in table 7.

Table 9.--Estimated long-term mean monthly discharges and errors at Big Creek near Emigrant (station 12)

Month	Long-term mean monthly discharge of Big Creek, in cubic feet per second: Estimated[1]	Actual	Percent difference
October	35	31	+13
November	27	28	-4
December	22	25	-12
January	19	23	-17
February	18	22	-18
March	20	24	-17
April	35	42	-17
May	144	133	+8
June	280	247	+13
July	170	104	+63
August	78	36	+117
September	47	30	+57

[1] Estimated using monthly flow distribution of Yellowstone River at Corwin Springs.

An additional check on the accuracy of the long-term mean annual discharge estimates was made using the two years of recorded data for Bear Creek (site 3). In this instance, the annual mean discharge of Bear Creek for wateryear 1947 was 73.6 ft^3/s. For that same year, the annual mean discharge of the Yellowstone River at Corwin Springs was 1.09 times the annual discharge for the base period, water-years 1934-83. Dividing the mean discharge of Bear Creek for wateryear 1947 by 1.09 provides an estimate for the long-term mean annual discharge of Bear Creek of 67.5 ft^3/s. Similarly, the recorded annual mean discharge of Bear Creek for water-year 1948 was 60.0 ft^3/s. The annual mean discharge of the Yellowstone River at Corwin Springs for wateryear 1948 was 1.08 times the 1934-83 mean annual discharge. The estimated long-term mean annual discharge for Bear Creek using the data for wateryear 1948 is, therefore, 60.0 divided by 1.08, or 55.6 ft^3/s. These two estimates for long-term mean annual discharge of Bear Creek thus range from 55.6 to 67.5 ft^3/s with the estimate made using the measured data for wateryears 1982-83 (60.0 ft^3/s) falling about midway between. It thus appears likely that the true value of the long-term mean annual discharge for Bear Creek is within about 20 percent of the estimate made using the measured data for wateryears 1982-83.

The flow record for the discontinued gaging station downstream from the Mill Creek measurement site near Pray (site 16) also was used to check the accuracy of the estimated mean monthly discharges for the nonirrigation season. The results of the mean monthly discharge comparison are given in table 10. The differences between mean monthly discharges determined from the flow record and mean monthly discharges estimated using the techniques described in the report range from -21.2 to +79.5 percent. Thus, differences are comparable to the differences obtained using the Big Creek flow record (table 9).

Table 10.--Accuracy of estimated mean monthly discharges at Mill Creek near Pray (site 16)

[ft^3/s, cubic feet per second]

Month	Estimated mean discharge using Big Creek record (ft^3/s)	Mean discharge from record (ft^3/s)	Percent difference
January	30.0	31.4	-4.5
February	29.0	30.2	-4.0
March	31.0	27.3	+13.6
April	45.0	57.1	-21.2
May	365.0	294.2	+24.1
June	785.0	[1]724.6	--
July	350.0	[1]215.5	--
August	140.0	[1]45.8	--
September	85.0	[1]34.2	--
October	70.0	39.0	+79.5
November	65.0	40.9	+58.9
December	55.0	40.2	+36.8

[1] Mean discharge affected by irrigation diversions.

Geographic variations in mean annual runoff

The long-term mean annual discharge determined for each measurement site and the gaging station on Big Creek was converted to inches of annual runoff and plotted at the centroid of each drainage basin on a map of the study area. Lines of equal mean annual runoff then were drawn on the map (figure 4). Based on the limited number of data points, mean annual runoff appears to increase with increasing elevation. The largest values of mean annual runoff occur in the Bear Creek drainage (sites 2 and 3) northeast of Jardine, Montana. The smallest value of mean annual runoff occurs in Cedar Creek (site 8) which, ironically, is the drainage adjacent to Bear Creek. The small value for Cedar Creek may be due to a geologic anomaly, because all adjacent measurement sites have markedly larger values of mean annual runoff.

Almost all streams in the study area are used extensively for irrigation after they leave the mountains and enter the valley floor. The mean annual runoff map is applicable only to streams that are not affected by diversion, so the reader is advised to use the map with caution in the valley floor area.

Equations for estimating streamflow characteristics

Multiple linear regression techniques were used to develop estimating equations for mean annual discharge and for various points on the flow-duration curve. A log-linear equation of the following form was used for the mean annual discharge equations:

$$Q_A = aA^{b1} P^{b2} \quad (1)$$

where:

Q_A is the mean annual discharge, in cubic feet per second;
A is the drainage area, in square miles;
P is the mean annual precipitation, in inches;
a is the regression constant; and
$b1$ and $b2$ are regression coefficients.

The regression variables for each measurement site and gaging station in the study area are listed in table 4. The Yellowstone River at Corwin Springs (station 4) was not used in the regression analysis because its drainage area is substantially larger than that of any of the measurement sites and the other gaging station. Also, the Bear Creek measurement sites (2 and 3) were omitted from the regression analysis because of an apparent anomaly in the mean annual precipitation values in the Bear Creek drainage. Although a mean annual precipitation value of 33 inches is given for each of the Bear Creek measurement sites, the mean annual runoff values range from about 23 to 37 inches (table 4). Because mean annual runoff must be less than the mean annual precipitation, the generalized precipitation values in the Bear Creek basin must be incorrect.

The regression equation for estimating long-term mean annual discharge in all parts of the study area, except the Bear Creek drainage, is:

$$Q_A = 0.0159\ A^{1.082}\ P^{1.048} \quad (2)$$

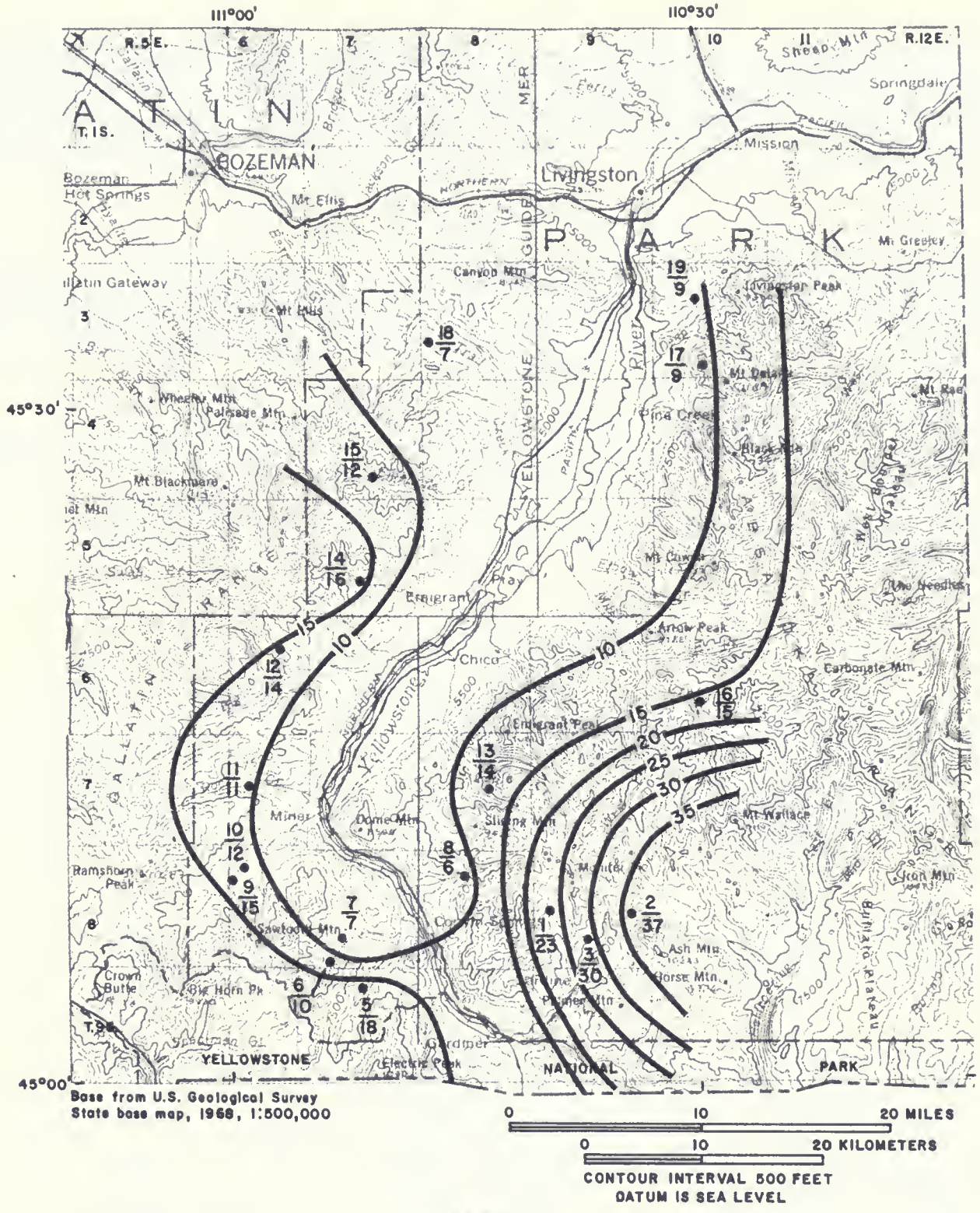

Figure 4.--Mean annual runoff

where the terms are as previously defined. The coefficient of determination (R^2) is 0.896, and the standard error of estimate is 28 percent. A regression equation using drainage area as the only independent variable also was derived, so that mean annual discharge could be estimated for the Bear Creek drainage area. This equation was based on all measurement-site and gaging-station data except those for the Yellowstone River and is as follows:

$$Q_A = 1.114\ A^{0.952} \qquad (3)$$

where the coefficient of determination is 0.641 and the standard error of estimate is 54 percent. As might be expected, this equation does not fit the data as well as the equation using the additional precipitation variable. It does, however, provide the user with a means for estimating annual discharge when the mean annual precipitation values are thought to be in error.

Regression equations relating discharges of various exceedance percentages to long-term mean annual discharge also were derived. Again, data from all sites except station 4 (the Yellowstone River at Corwin Springs) were used in the regression analysis. The equations and the coefficients of determination are presented in table 11.

Table 11.--Estimating equations for flow-duration-curve discharges

Discharge, in cubic feet per second, for indicated exceedance percentage	Equation	Coefficient of determination (r^2)
Q_{10}	$3.300\ Q_A^{0.965}$	0.901
Q_{20}	$1.399\ Q_A^{1.039}$	.948
Q_{30}	$0.801\ Q_A^{1.054}$	.843
Q_{40}	$0.523\ Q_A^{1.063}$	.769
Q_{50}	$0.383\ Q_A^{1.060}$	.720
Q_{60}	$0.293\ Q_A^{1.060}$	.683
Q_{70}	$0.225\ Q_A^{1.066}$	.656
Q_{80}	$0.175\ Q_A^{1.073}$	.639
Q_{90}	$0.137\ Q_A^{1.080}$	.623
Q_{95}	$0.116\ Q_A^{1.088}$	.616

The equations in table 11 are comparable to the equations derived for Region 1 in western Montana (U.S. Geological Survey 1985). The coefficients of determination, however, are substantially smaller in the upper Yellowstone drainage. The site-to-site variability of streamflow is evidently greater in the upper Yellowstone drainage than in western Montana.

The regression equations for estimating mean annual discharge and flow-duration-curve discharges are limited to the range of data used to derive the equations. If the equations are used for streams with drainage areas less than 9.77 mi^2 or greater than 148 mi^2 (table 4), the results may be less reliable. Similarly, the equations may not be reliable if used in areas where the mean annual precipitation is less than 23 inches or greater than 38 inches.

The equations also are not applicable to streams with unusual flow characteristics due to localized geologic anomalies. Thus, the equations will not provide reliable estimates for streams that are affected by springs or for streams that lose most of their flow through permeable streambeds.

Most important perhaps, the estimating equations are not applicable to streams that are regulated or have upstream diversions. Their use is thus limited in the valley floor area where diversions for irrigation occur on almost every stream.

SUMMARY AND CONCLUSIONS

Once-monthly streamflow measurements were made at 17 sites in the upper Yellowstone basin from November 1982 through October 1983. The measurements were used to develop estimates of streamflow characteristics including long-term mean annual discharge, mean monthly discharge, and various points on the flow-duration curves at each site. The estimated average error of the long-term estimates is $\pm$20 percent for the mean annual discharge and the flow-duration curve, and $\pm$100 percent for the mean monthly discharge.

A mean annual runoff map was prepared using the long-term mean annual discharge estimated for each site. The map shows that mean annual runoff appears to increase with increasing elevation, and ranges from about 6 inches on the valley floor to about 37 inches in the Bear Creek drainage in the western part of the study area.

A regression equation relating long-term mean annual discharge to drainage area and mean annual precipitation also was developed using the estimates from 15 measurement sites plus long-term data from 1 gaging station in the area (station 12). Because the mean annual precipitation data in the Bear Creek drainage are incorrect, three measurement sites in that area were not used in the regression analysis. A separate regression equation, including all Bear Creek measurement-site data, but excluding mean annual precipitation as a variable, also was derived. The regression equation using both drainage area and mean annual precipitation had a coefficient of determination (R^2) of 0.896 and a standard error of estimate of 28 percent. The regression equation using only drainage area had a coefficient of determination of 0.641 and a standard error of estimate of 54 percent.

Regression equations relating flows of 10-, 20-, 30-, 40-, 50-, 60-, 70-, 80-, 90-, and 95-percent exceedance probability to long-term mean annual discharge also were developed. The coefficients of determination for these equations ranged from 0.616 to 0.948. The smallest coefficient of determination occurred in the estimating equation for Q_{95}, and the largest coefficient of determination occurred in the estimating equation for Q_{20}. The derived regression equations were similar to equations developed for Region 1 in western Montana, but the site-to-site variability of streamflow is greater in the upper Yellowstone River basin.

The regression equations are not applicable to sites where the drainage area or mean annual precipitation is outside the range of values used to derive the equations. Sites that are affected by springs or that lose water because of unique geologic conditions also are outside the scope of the derived equations. Finally, the equations are not applicable to streams that are regulated or have upstream diversions.

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MEASUREMENT-SITE DESCRIPTIONS AND STREAMFLOW DATA

[ft^3/s, cubic feet per second; ft, feet; mi, miles]

Site No. (fig. 1)	Stream name	Location	Date	Discharge (ft^3/s)
1	North Fork Bear Creek	Lat 45°04'30", long 110°37'59", in NW¼SW¼SW¼ sec. 4, T. 9 S., R. 9 E., Park County, at footbridge at end of county road in Jardine, Montana	11-15-82	10.5
			12-13-82	7.94
			01-18-83	5.46
			02-15-83	4.32
			03-16-83	3.83
			04-14-83	2.18
			05-18-83	8.88
			06-01-83	101
			06-14-83	96.4
			07-14-83	54.7
			08-15-83	14.3
			09-16-83	9.83
			10-13-83	13.5
2	Bear Creek above North Fork Bear Creek	Lat 45°04'25", long 110°37'50", in SW¼SE¼SW¼ sec. 4, T. 9 S., R. 9 E., Park County, at mouth of North Fork Bear Creek in Jardine, Montana	11-15-82	10.8
			12-13-82	6.66
			01-18-83	3.47
			02-15-83	6.08
			03-16-83	6.17
			04-14-83	5.60
			05-18-83	16.4
			06-01-83	139
			07-14-83	129
			08-15-83	25.9
			09-16-83	13.9
			10-13-83	23.4
3	Bear Creek	Lat 45°04'25", long 110°37'50", in SW¼SE¼SW¼ sec. 4, T. 9 S., R. 9 E., Park County, 200 ft downstream from mouth of North Fork Bear Creek in Jardine, Montana	11-15-82	21.3
			12-13-82	14.6
			01-18-83	8.93
			02-15-83	10.4
			03-16-83	10.0
			04-14-83	7.78
			05-18-83	25.3
			06-01-83	240
			07-14-83	184
			08-15-83	40.2
			09-16-83	23.7
			10-13-83	36.9

MEASUREMENT-SITE DESCRIPTIONS AND STREAMFLOW DATA--Continued

Site No. (fig. 1)	Stream name	Location	Date	Discharge (ft^3/s)
5	Mol Heron Creek	Lat 45°06'34", long 110°49'09", in SW¼SW¼NW¼ sec. 25, T. 8 S., R. 7 E., Park County, at culvert 50 ft upstream from mouth of Cinnabar Creek, 1.5 mi upstream from mouth, and 1.5 mi west of Corwin Springs, Montana	11-15-82	17.6
			12-13-82	16.5
			01-18-83	10.1
			02-15-83	10.4
			03-15-83	9.19
			04-13-83	11.9
			05-17-83	10.8
			06-01-83	55.2
			06-14-83	71.2
			07-13-83	52.0
			08-15-83	19.2
			09-15-83	13.4
			10-13-83	17.1
6	Cinnabar Creek above Cottonwood Creek	Lat 45°06'39", long 110°51'33", in NW¼SE¼NW¼ sec. 27, T. 8 S., R. 7 E., Park County, 0.5 mi upstream from Cottonwood Creek, 2 mi upstream from mouth, and 3.6 mi west of Corwin Springs, Montana	11-15-82	8.48
			12-13-82	6.70
			01-18-83	5.27
			02-15-83	4.71
			03-15-83	5.71
			04-13-83	4.99
			05-17-83	7.33
			06-01-83	29.6
			06-14-83	25.0
			07-13-83	10.3
			08-15-83	10.1
			09-15-83	7.35
			10-13-83	9.08
7	Cinnabar Creek at mouth	Lat 45°06'34", long 110°49'10", in SW¼SW¼NW¼ sec. 25, T. 8 S., R. 7 E., Park County, at culvert at mouth, 1.5 mi west of Corwin Springs, Montana	11-15-82	12.5
			12-14-82	7.92
			01-18-83	7.01
			02-15-83	6.39
			03-15-83	7.64
			04-13-83	8.00
			05-17-83	9.34
			06-01-83	28.6
			06-14-83	25.7
			07-13-83	12.4
			08-15-83	12.5
			09-15-83	8.25
			10-13-83	8.15

MEASUREMENT-SITE DESCRIPTIONS AND STREAMFLOW DATA--Continued

Site No. (fig. 1)	Stream name	Location	Date	Discharge (ft^3/s)
8	Cedar Creek	Lat 45°08'35", long 110°48'45", in SE¼NE¼NW¼ sec. 13, T. 8 S., R. 7 E., Park County, at culverts on U.S. Highway 89, 2.5 mi northwest of Corwin Springs, Montana	11-16-82	7.71
			12-14-82	6.87
			01-18-83	5.74
			02-15-83	6.40
			03-15-83	5.14
			04-13-83	6.34
			05-17-83	4.37
			06-01-83	17.7
			06-14-83	26.3
			07-14-83	21.3
			08-15-83	1.16
			09-15-83	.89
			10-13-83	8.09
9	Tom Miner Creek above Canyon Creek	Lat 45°11'22", long 110°56'03", in NW¼NW¼NW¼ sec. 36, T. 7 S, R. 6 E., Park County, 300 ft upstream from Canyon Creek, 1.8 mi upstream from mouth, and 9 mi northwest of Corwin Springs, Montana	11-16-82	[1]53.0
			12-14-82	28.9
			01-19-83	23.5
			02-15-83	21.2
			03-15-83	29.1
			04-13-83	27.1
			05-17-83	49.1
			06-01-83	168
			06-15-83	164
			07-13-83	97.2
			08-15-83	52.6
			09-15-83	30.7
			10-13-83	35.0
10	Tom Miner Creek at mouth	Lat 45°11'57", long 110°54'28", in SE¼SW¼NE¼ sec. 30, T. 7 S., R. 7 E., Park County, at bridge near mouth on county road, 0.5 mi south of bridge on Yellowstone River, and 8.5 mi northwest of Corwin Springs, Montana	11-16-82	52.9
			12-14-82	35.0
			01-19-83	23.2
			02-15-83	21.1
			03-15-83	29.4
			04-13-83	23.9
			05-17-83	43.6
			06-01-83	165
			06-15-83	166
			07-13-83	83.8
			08-15-83	33.0
			09-15-83	21.1
			10-13-83	27.9

MEASUREMENT-SITE DESCRIPTIONS AND STREAMFLOW DATA--Continued

Site No. (fig. 1)	Stream name	Location	Date	Discharge (ft^3/s)
11	Rock Creek	Lat 45°12'39", long 110°54'11", in NE¼NW¼SE¼ sec. 19, T. 7 S., R. 7 E., Park County, at bridge at mouth on county road, 0.4 mi north of bridge on Yellowstone River, and 9 mi northwest of Corwin Springs, Montana	11-16-82	10.4
			12-14-82	7.77
			01-19-83	6.91
			02-16-83	4.61
			03-15-83	6.21
			04-13-83	6.64
			05-17-83	12.6
			06-01-83	123
			06-14-83	110
			07-13-83	50.9
			08-15-83	10.1
			09-15-83	4.77
			10-13-83	6.52
13	Sixmile Creek	Lat 45°16'15", long 110°46'31", in SW¼SE¼NW¼ sec. 32, T. 6 S., R. 8 E., Park County, at bridge on county road, 3.5 mi upstream from mouth, and 7 mi south of Emigrant, Montana	11-16-82	12.5
			12-15-82	6.06
			01-19-83	9.33
			02-16-83	8.19
			03-15-83	9.52
			04-13-83	9.88
			05-17-83	16.1
			06-01-83	103
			06-14-83	138
			07-12-83	96.8
			08-15-83	28.0
			09-15-83	17.8
			10-14-83	22.1
14	Fridley Creek	Lat 45°21'38", long 110°47'58", in NE¼SW¼NE¼ sec. 36, T. 5 S., R. 7 E., Park County, 100 ft upstream from Miller Creek, 2.5 mi upstream from mouth, and 3.2 mi west of Emigrant, Montana	11-16-82	15.4
			12-15-82	7.63
			01-19-83	7.47
			02-16-83	6.91
			03-15-83	12.2
			04-13-83	9.11
			05-17-83	15.5
			06-01-83	56.2
			06-14-83	60.8
			07-13-83	29.2
			08-16-83	10.2
			09-15-83	9.09
			10-13-83	10.8

Site No. (fig. 1)	Stream name	Location	Date	Discharge (ft^3/s)
15	Eightmile Creek	Lat 45°26'15", long 110°43'40", in NE¼NW¼NW¼ sec. 3, T. 5 S., R. 8 E., Park County, at landowner's bridge, 1.3 mi west of Trail Creek Road, 2.5 mi downstream from Big Draw, and 4.5 mi west of Pray, Montana	11-16-82	20.6
			12-15-82	8.06
			01-20-83	18.8
			02-16-83	16.8
			03-14-83	20.4
			04-12-83	17.4
			05-16-83	[2]21.5
			05-31-83	[2]38.0
			06-13-83	[3]40.0
			07-13-83	[3]23.7
			08-16-83	[3]20.5
			09-14-83	[3]19.7
			10-14-83	[3]20.7
16	Mill Creek	Lat 45°20'11", long 110°35'19", in SE¼SE¼SW¼ sec. 2, T. 6 S., R. 9 E., Park County, at U.S. Forest Service boundary, 2 mi downstream from East Fork Mill Creek, 6 mi upstream from old U.S. Highway 89, and 5.5 mi southeast of Pray, Montana	11-17-82	77.8
			12-15-82	23.1
			01-20-83	25.8
			02-14-83	36.3
			03-14-83	48.0
			04-12-83	38.0
			05-16-83	80.9
			05-31-83	567
			06-15-83	583
			07-12-83	538
			08-15-83	111
			09-14-83	64.1
			10-12-83	89.9
17	Deep Creek	Lat 45°32'31", long 110°32'24", in SW¼SE¼SW¼ sec. 30, T. 3 S., R. 10 E., Park County, at bridge on county road, 1 mi east of old U.S. Highway 89, and 8 mi south of Livingston, Montana	11-17-82	1.03
			12-16-82	1.38
			01-17-83	.65
			02-14-83	.55
			03-14-83	.75
			04-12-83	.62
			05-16-83	1.38
			05-31-83	122
			06-13-83	50.9
			07-12-83	49.1
			08-15-83	2.55
			09-14-83	1.44
			10-12-83	5.59

MEASUREMENT-SITE DESCRIPTIONS AND STREAMFLOW DATA--Continued

Site No. (fig. 1)	Stream name	Location	Date	Discharge (ft^3/s)
18	Trail Creek	Lat 45°29'58", long 110°42'03", in NW¼SW¼SE¼ sec. 11, T. 4 S., R. 8 E., Park County, at culvert on county road, 100 ft upstream from Pine Creek, and 13 mi southwest of Livingston, Montana	11-16-82	11.7
			12-15-82	4.61
			01-20-83	6.33
			02-16-83	12.8
			03-14-83	16.8
			04-12-83	11.8
			05-16-83	27.0
			05-31-83	62.4
			06-13-83	50.1
			07-12-83	23.0
			08-16-83	10.6
			09-14-83	8.28
			10-12-83	7.37
19	Suce Creek	Lat 45°34'01", long 110°33'30", in SW¼NW¼NE¼ sec. 24, T. 3 S., R. 9 E., Park County, at bridge on old U.S. Highway 89, 1 mi upstream from mouth, and 6.5 mi south of Livingston, Montana	11-17-82	1.78
			12-16-82	0.84
			01-17-83	1.04
			02-14-83	0.97
			03-14-83	2.79
			04-12-83	1.97
			05-16-83	3.03
			05-31-83	37.2
			06-13-83	[4]39.2
			07-12-83	[4]8.41
			08-16-83	[4]5.30
			09-14-83	[4]3.41
			10-12-83	1.56

[1] Estimated.
[2] Partly estimated.
[3] Measured 2 mi upstream.
[4] Measured at U.S. Forest Service boundary, 2 mi upstream.